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Office of Program Director
for Surveillance
Washington, DC 20591

Impact of Shutting Down En Route Primary Radars within CONUS Interior

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Final Report
June 1993

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13. ABSTRACT (Maximum 200 words) The impact on the Air Traffic Control (ATC) operations resulting from the shutdown of all en route primary radars (except for ARSR-4s) within the CONUS interior will result in loss of real-time weather data and aircraft skin tracking, over 33 percent primary surveillance loss of coverage in the CONUS, and an increase in the accident rate of one accident in 11 years as predicted on recent statistics. The report concludes that real-time weather data, while of limited quality, must be retained until it can be replaced by data from the NEXRAD weather radar or other weather data source. Ability to track non-transponder equipped aircraft is significant but less critical and can be minimized by other system improvements. These include: better beacon radar (Mode S) in combination with Traffic Alert and Collision Avoidance System (TCAS) and Automatic Dependent Surveillance (ADS); increased transponder equipage; reduced altitude for non-transponder equipped aircraft to 10 thousand feet; increased DF network to 370 sites; and better siting of beacon-only antennas. Based on current availability, projections (derived from Capital Investment Plan (CIP) schedules), the most feasible en route primary radar shutdown date is the year 2008. If weather data from external sources can be made available on controllers' displays before that time (for example, by 1998 when ISSS is installed), that data can be advanced.					
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PREFACE

The work described in this report was performed under Project Plan Agreement FA-3M5 for the Federal Aviation Administration (FAA), Program Office for En Route Radar. The Sponsor of the project, Richard J. Lay, ANR-400, directed the work study effort.

The work was performed by the Department of Transportation/Research and Special Programs Administration/Volpe National Transportation Systems Center, Surveillance and Sensor Division. This report presents a comprehensive study of the impact on en route primary radar shutdown on Air Traffic Control (ATC) operations.

The author wishes to thank Richard J. Lay, the Program Manager for En Route Radar, for his support and guidance during this study and Edward A. Spitzer, Chief, Surveillance and Sensors Division, and Paul E. Manning, DTS-53, for this review and valuable suggestions. Especially grateful acknowledgements go to Dr. E. Michael Geyer and Alan G. Cameron, The Analytic Sciences Corporation (TASC), for their technical inputs to this study. Also, appreciation goes to Douglas Hodgkins, ASE-300 and William G. Collins, FAA ANR-102 for their valuable technical inputs; to Diane Essig-Hooper, APM-130, for verifying the FY-93 CIP cost figures; to Mark Clark and Louis Fisher, Martin Marietta, for their detailed cost estimates; and to Henry J. Wychorski, UNISYS, for his contribution to the Remote Maintenance Monitoring System (RMMS) section. The draft report was reviewed by Teddy Boatright, ANR-110, James D. Duffer, ANR-110, Billy Holland, ANR-110, Michael J. Polchert, ANR-110, Theodore H. Weyrauch, ANR-110, and Arthur L. Levy, ANR-150. Their valuable contributions and comments to improve this report are appreciated. Special thanks go to Anita Graffeo, EG&G Dynatrend, for editing and preparing this document.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
 1 foot (ft) = 30 centimeters (cm)
 1 yard (yd) = 0.9 meter (m)
 1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in²) = 6.5 square centimeters (cm²)
 1 square foot (sq ft, ft²) = 0.09 square meter (m²)
 1 square yard (sq yd, yd²) = 0.8 square meter (m²)
 1 square mile (sq mi, mi²) = 2.6 square kilometers (km²)
 1 acre = 0.4 hectares (he) = 4,000 square meters (m²)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
 1 pound (lb) = .45 kilogram (kg)
 1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
 1 tablespoon (tbsp) = 15 milliliters (ml)
 1 fluid ounce (fl oz) = 30 milliliters (ml)
 1 cup (c) = 0.24 liter (l)
 1 pint (pt) = 0.47 liter (l)
 1 quart (qt) = 0.96 liter (l)
 1 gallon (gal) = 3.8 liters (l)
 1 cubic foot (cu ft, ft³) = 0.03 cubic meter (m³)
 1 cubic yard (cu yd, yd³) = 0.76 cubic meter (m³)

TEMPERATURE (EXACT)

$$[(x-32)(5/9)]^{\circ}\text{F} = y^{\circ}\text{C}$$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
 1 centimeter (cm) = 0.4 inch (in)
 1 meter (m) = 3.3 feet (ft)
 1 meter (m) = 1.1 yards (yd)
 1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm²) = 0.16 square inch (sq in, in²)
 1 square meter (m²) = 1.2 square yards (sq yd, yd²)
 1 square kilometer (km²) = 0.4 square mile (sq mi, mi²)
 1 hectare (he) = 10,000 square meters (m²) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
 1 kilogram (kg) = 2.2 pounds (lb)
 1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

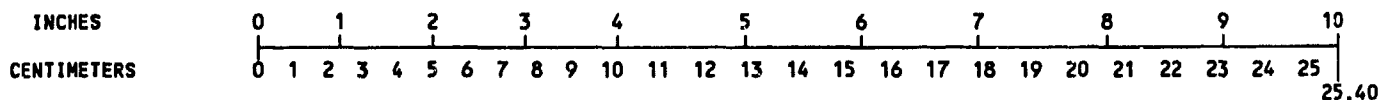
VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
 1 liter (l) = 2.1 pints (pt)
 1 liter (l) = 1.06 quarts (qt)
 1 liter (l) = 0.26 gallon (gal)
 1 cubic meter (m³) = 36 cubic feet (cu ft, ft³)
 1 cubic meter (m³) = 1.3 cubic yards (cu yd, yd³)

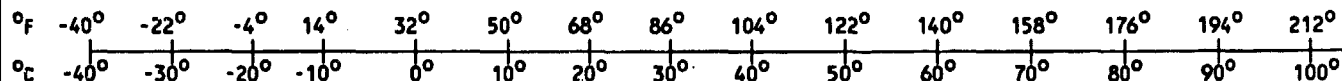
TEMPERATURE (EXACT)

$$[(9/5) y + 32]^{\circ}\text{C} = x^{\circ}\text{F}$$

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For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price \$2.50. SD Catalog No. C13 10286.

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EXECUTIVE SUMMARY

E.1 INTRODUCTION

The Federal Aviation Administration (FAA) is currently considering shutting down (removing) its en route primary radars located in the interior of the Continental United States (CONUS). The contemplated shutdown includes all AN/FPS-20s, and all Air Route Surveillance Radars (ARSR-1s, ARSR-2s and ARSR-3s) now planned for use in the year 2000 (83 total). It does not include the 39 new ARSR-4s which will be located on the perimeter of the CONUS and which will also provide air defense and drug interdiction data as part of the FAA/DOD Joint Surveillance System (JSS). Locations where primary radar is removed would become beacon-only sites, and would be upgraded to Mode S according to current schedules.

This report assesses the impact of the contemplated shutdown. Specifically, it:

- Describes the functional Air Traffic Control (ATC) capabilities performed by primary radars, assesses their relative values, and identifies candidate replacement systems/procedures/processes (Sections 2 and E.2).
- Identifies the equipment involved in the contemplated shutdown and the associated cost impact (Sections 3 and E.3).
- Expresses tentative conclusions (Sections 4 and E.4).

E.2 PRIMARY RADAR FUNCTIONS

As a part of the National Airspace System (NAS) ATC system, primary radar performs five specific functions. In decreasing order of importance, these functions are:

- Detection and display of real-time weather information on the controller's Plan View Display (PVD).
- Detection of nontransponder-equipped aircraft.
- Backup to the Air Traffic Control Radio Beacon System (ATCRBS) secondary radar in the event of aircraft transponder failure.

- Backup in the event of ATCRBS ground equipment failure.
- Enhancement of secondary radar surveillance data.

These functions are addressed individually below.

E.2.1 Weather Detection

Primary radar indicates the presence of precipitation within the coverage region, and *currently is the only source of real-time weather data available at the controller's PVD.* Weather data from other sources, including National Weather Service (NWS) radars, are available within centers, but the information is somewhat delayed and the displays are not readily accessible to all controllers. The quality of primary-radar-derived weather data for the ARSR-1 and FPS-20 is mediocre: two levels of precipitation intensity are depicted, there is no altitude discrimination, and "false alarms" (overprediction of precipitation) are common. However, the ARSR-4 and ARSR-3 radars have a separate weather channel and provide information similar to NEXRAD. One added advantage is that the data is not mosaic and shows location of actual cells. Despite these shortcomings in the ARSR-1 and FPS-20 radars, it is not prudent to remove the current capability without providing a replacement. Current FAA plans are to provide weather data to controllers using NEXRAD as the sensor, the Real-time Weather Processor (RWP) as the distribution system, and the Advanced Automation System (AAS) Area Control Computer Complex (ACCC) as the display device. Expected date for completion is the 1998-2008 time frame. It is likely that a project limited to providing real-time weather to controllers, possibly using NWS radars, phone lines, and the AAS Initial Sector Suite System (ISSS) -- could achieve this capability several years earlier.

E.2.2 Nontransponder Aircraft Surveillance

Primary radar is the only source of surveillance data for aircraft not equipped with a transponder. It is estimated¹ that deactivation of the en route primary radars not part of the JSS would remove surveillance coverage of nontransponder equipped aircraft below 10,000 feet over

¹Yesley, J.M., and Kitterman, R.W., *Effect of Primary Surveillance Radar on Mid-Air Collision Risk in the En Route Environment*, November 1991.

33 percent of the CONUS. The remaining 67 percent of the CONUS would either continue to be covered by terminal or JSS radars, or does not now have coverage (the contemplated deactivation would also remove coverage up to 20,000 feet. While nontransponder equipped aircraft are not authorized to be at these altitudes, occasional blunders do occur). Without primary radar, controllers would no longer be able to provide advisories to Instrument Flight Rules (IFR) aircraft concerning the presence of Visual Flight Rules (VFR) traffic in these regions. The referenced study considered 23 mid-air collisions over a 7-year span, and found that: the great majority (17) occurred below 6000 feet; and of the remaining 6 collisions, 4 were VFR/VFR. It predicts that shutting down en route radars will cause a negligible increase in the rate of IFR/VFR mid-air collisions (one additional accident in the next 30 years). The best alternative to primary radar for this function is increased transponder equipage. Currently, approximately 70 percent of general aviation is transponder equipped. Equipage is expected to rise to approximately 80 percent over the next decade, as a result of both airspace usage restrictions and the declining cost of avionics units.

E.2.3 Backup in Event of Transponder Failure

Primary radar is a backup source of surveillance data in the event of an IFR aircraft transponder failure. For the primary radar to be effective, the aircraft must be sufficiently large and separated from other traffic. Transponder failures are typically observed once every few days at a center, involving either small general aviation aircraft (in which case primary radar is marginally effective) or larger military aircraft with older equipment (in which case primary radar is effective).

A recent study² addressed the special case of lost aircraft. Of 266 accidents considered, only 3 were found to have some dependence on primary radar (virtually every accident involved an inexperienced pilot who did not request help until fuel became short). It concluded that removal of primary radar is not expected to have a significant impact on the accident rate -- one additional accident in the next 18 years is predicted. Alternatives to primary radar for this

²Yesley, J.M., and Kitterman, R.W., *Impact of Primary Surveillance Radar on Lost Aircraft Accident Rate in the En Route Environment*, November 1991.

application are: (1) aircraft reverts to VFR if possible; (2) aircraft voice-reporting of position; and (3) direction finding based on aircraft voice reports.

E.2.4 Backup in Event of Interrogator Failure

Primary radar can also serve as a backup source of surveillance data in the event of a secondary radar ground equipment failure. Situations when this backup is used, in which beacon radar fails while the search radar remains operational, are rare. Moreover, much of the CONUS airspace has redundant ATCRBS coverage. Alternatives to primary radar for this application are additional beacon-only installations, and a future Automatic Dependent Surveillance (ADS) system (possibly based on use of a Mode S data link).

E.2.5 Enhancement of Secondary Radar Data

When primary and secondary radar indicate a target at the same location, the "radar reinforcement" bit is set in the secondary target message transmitted from the radar site to the center. When the controller suspects a "false target" is indicated by the beacon, he/she can employ the reinforcement bit as a crosscheck. There are several alternative ways of improving the quality of data derived from the beacon radar through additional signal processing. Some of these techniques (e.g., mapping of the site-specific multipath geometry) have been implemented for terminal radars and in Mode S, but none has been used for the en route ATCRBS system.

E.3 EQUIPMENT AND COST IMPACT

E.3.1 Equipment Involved

The following major mechanical/structural changes are expected to be required in order to convert an existing dual-radar installation to a beacon-only site:

- Removal of primary radar electronics from the equipment room.
- Removal of the radome.

- Replacement of the common pedestal, primary radar antenna, and secondary radar antenna by a less massive pedestal and a new secondary antenna, capable of operation without a radome.

The massive pedestal currently installed is required to support the large primary radar antenna. Elimination of the latter would enable a cheaper, more easily maintained pedestal to be installed, and would allow the secondary antenna to rotate at a faster rate. The current 25- to 30- year old radomes would not be needed with only a secondary antenna installed. En route radar sites can be converted from dual-radar to beacon-only installations with virtually no modifications to the secondary radar electronics, because the ATCRBS systems were designed with the capability of operating independently.

E.3.2 Estimated Costs

The savings to be realized by removing the primary radars immediately are estimated relative to retaining the primary radars until 2008, when display of real-time weather data at the controller's workstation will be available. Three categories of costs are involved:

- *\$124.5M Expenditures* -- for removing old primary radar equipment from, and cleaning up 83 sites, at \$1.5M per site. (Personnel relocation costs not included.)
- *\$336.0M Savings* -- foregone expenditures for relevant Capital Investment Plan (CIP) projects (see Table E-1).
- *\$67.5M Savings* -- foregone expenditures for maintenance over 15 years at \$4.5M per year.

The above figures do not reflect savings due to elimination of watch standers for primary radar sites. Remote Maintenance Monitoring (RMM) capabilities, planned for installation during the 1990s, will eliminate these positions in a phased manner. Cost for watchstanders is currently \$18M per year.

E.4 CONCLUSIONS

The estimated net savings resulting from timely primary radar shutdown, and cancellation of planned programs to improve radar performance is therefore approximately \$279.0M, over

**Table E-1. CIP En Route Radar Program Costs
(FY-93 Cost Estimates)**

PROJECT	NAME / DESCRIPTION	AMOUNT
24-15	Long-Range Radar (LRR) Program 10 ARSR-3 "leapfrog" relocations LRRs relocated as required (39 ARSR-4s being procured not included in "amount")	\$34.6M
44-39	<i>Relocate Air Route Surveillance Radars</i> Approximately 2 sites/year to be relocated	\$56.7M
44-40	<i>Long-Range Radar Improvements</i> Improvements to older LRRs: controls for ARSR-1 and -2s, cable trays cleaned-up, grounding upgraded	\$186.2
44-42	<i>Long-Range Radar Radome Replacement</i> Replace radomes at all existing LRR sites: most are 25 to 30 years old (signal distortion and maintenance are issues), and will not accommodate taller Mode S antenna	\$31.0M
44-43	<i>Radar Pedestal Vibration Analysis</i> Install vibration sensors and analysis equipment, in order to better manage maintenance activities	\$0.5M
	Solid State Transmitter Program	\$27.0M

the 15-year period 1993-2008. This total includes only savings derived from elimination of primary radar coverage, and does *not* account for the costs of planned programs to augment secondary radar coverage and performance (for example, CIPs 24-12, 44-45, and 44-46) or otherwise improve surveillance (ADS). To the extent that additional improvements to the remaining surveillance system would be appropriate to compensate for loss of primary radar, a case can be made for including a portion of their costs. Since such improvements have not yet been defined, there is no means of estimating these costs at present, and therefore they were *not* included.

The functions that primary radar presently provides are summarized in Table E-2. These would either be eliminated or provided by other means if the primary surveillance function was discontinued. The table includes estimates of when such alternative means would become available.

Table E-2. Summary of En Route Primary Radar Functions

FUNCTION	NEED	ALTERNATIVES	AVAILABLE
Real-Time Weather Detection	High to Medium	NEXRAD/RWP/AAS New focused program	1998-2008 not planned
Nontransponder Aircraft Detection	Medium to Low	Increased transponder equipage ADS (or later CIS)	2000 unclear
Backup for Transponder Failure	Medium to Low	Voice position report Communications direction finding VFR operation	now now now
Backup for ATCRBS Ground Equipment Failure	Low	Additional secondary sites ADS (or later CIS)	not planned unclear
Improvement of Secondary Data	Low	Processing improvements	in Mode S

A compelling, well-documented case for retaining non-JSS primary radars is not evident. Search radar does not perform any of the above functions extremely well, and credible studies indicate that a shutdown would result in only one additional accident in the next 11 years. On the other hand, shutting down these radars before replacement systems are on-line would diminish the margin of safety, if only by a small amount. While only a very small increase in the accident rate is predicted, other measures in ATC performance, such as controller situational awareness and ability to prevent near misses involving nontransponder aircraft, will likely be impacted to a greater degree.

The most prudent course of action appears to be to retain non-JSS primary radars until full functional replacements, systems which meet or exceed present search radar capabilities, are operational. If this tack is taken, the availability of a alternate means of presenting real-time weather information on the controller's screen will be a major determinant of when primary

radar can be decommissioned. Several current and planned programs (ISSS, ACCC, RWP, NEXRAD) impact that availability. Each must undergo significant development and integration, and some are currently being examined by the FAA. If early weather data display is desired, these programs should be modified accordingly.

1. INTRODUCTION

1.1 BACKGROUND

*Primary radar*³ is the foundation on which Air Traffic Control (ATC) surveillance was built. Originally the sole means of electronic surveillance, it was supplanted in the 1950s by *secondary radar*⁴, which now provides virtually all the surveillance data that drives the automated tracking and display processes used by ATC. Several new systems, in various stages of development or planning, may supplement or supplant the currently installed ATC Radar Beacon System (ATCRBS)⁵ secondary radars. These new systems/concepts include: *Mode S*, a secondary radar now being procured which employs the same rotating antenna and range measurement geometry as ATCRBS, but provides several performance improvements⁶; Automatic Dependent Surveillance (*ADS*), which employs a datalink to relay Global Positioning System (GPS) derived aircraft position information to control facilities; and Cooperative Independent Surveillance (*CIS*), a concept involving interrogation of aircraft from satellites. ADS is both a developmental system (for oceanic airspace, where a satellite datalink is used) and a proposed system (for en route airspace, where the datalink is undefined⁷).

1.2 OBJECTIVE

As new surveillance systems and concepts are advanced, the FAA must also reconsider the role and cost-effectiveness of existing assets. *The objective of the present report is to examine the option of shutting down en route primary radars within CONUS which will not be part of the JSS.* The FAA's Capital Investment Plan (CIP) projects 125 en route radar sites in

³Primary radar relies on reflections from the skin of the aircraft, and is also called search radar.

⁴Secondary radar relies on returns from a transponder in the aircraft, and is also called beacon radar.

⁵ATCRBS refers to the current Federal Aviation Administration (FAA) secondary radar equipments. ATCRBS provides: range, azimuth and identification code for all transponder-equipped aircraft; and, in addition, altitude for aircraft fitted with encoding altimeters.

⁶Ability to address individual aircraft, improved angular measurement accuracy, and air-ground datalink.

⁷Radio Technical Commission for Aeronautics (RTCA) is expected to conduct a study of ADS datalinks for Continental United States (CONUS) service during 1993 ("RTCA to Evaluate Data Link Systems," *Aviation Week and Space Technology*, February 1, 1993). Candidate links include air-ground in the VHF band (118-136 MHz), air-ground using Mode S (1030/1090 MHz), and satellite (approximately 1.6 GHz).

the year 2000. Of these, 39 sites, located near the CONUS perimeter, (and at the FAA training facility) would comprise the FAA/DOD (Department of Defense) JSS (Joint Surveillance System) and are not under consideration for shutdown. These sites are scheduled to receive new (Air Route Surveillance Radar) ARSR-4 primary radar equipment. An additional 3 ARSR-4s are planned for installation at overseas naval facilities, making a total of 42. Primary radars at the remaining 83 planned sites,⁸ located in the CONUS interior and having AN/FPS-20, ARSR-1, ARSR-2 and ARSR-3 equipment, are being considered for shutdown. Figure 1-1 depicts the en route primary radar sites as they existed in 1970. While no longer correct in detail, this figure accurately conveys the distribution of radar sites. All en route radar sites have collocated secondary radars (ATCBI-4 or -5 equipment in most cases), most of which are scheduled to be upgraded to Mode S as it becomes available.

1.3 APPROACH AND REPORT OVERVIEW

The option of shutting down non-JSS primary radars is investigated as follows:

- The functions performed by primary radar are summarized, and possible alternative systems and procedures for performing these functions are identified (Section 2).
- The equipment involved in the shutdown is described, including necessary modifications, and the direct cost impact is estimated (Section 3).
- Tentative conclusions are drawn (Section 4).

"Direct cost" in the second item refers to expenditures and savings associated with shutting down the radars themselves, and does not include costs for potential alternative systems.

⁸NAS-SS-1000, p. II-401, Table 20-12-2-1.

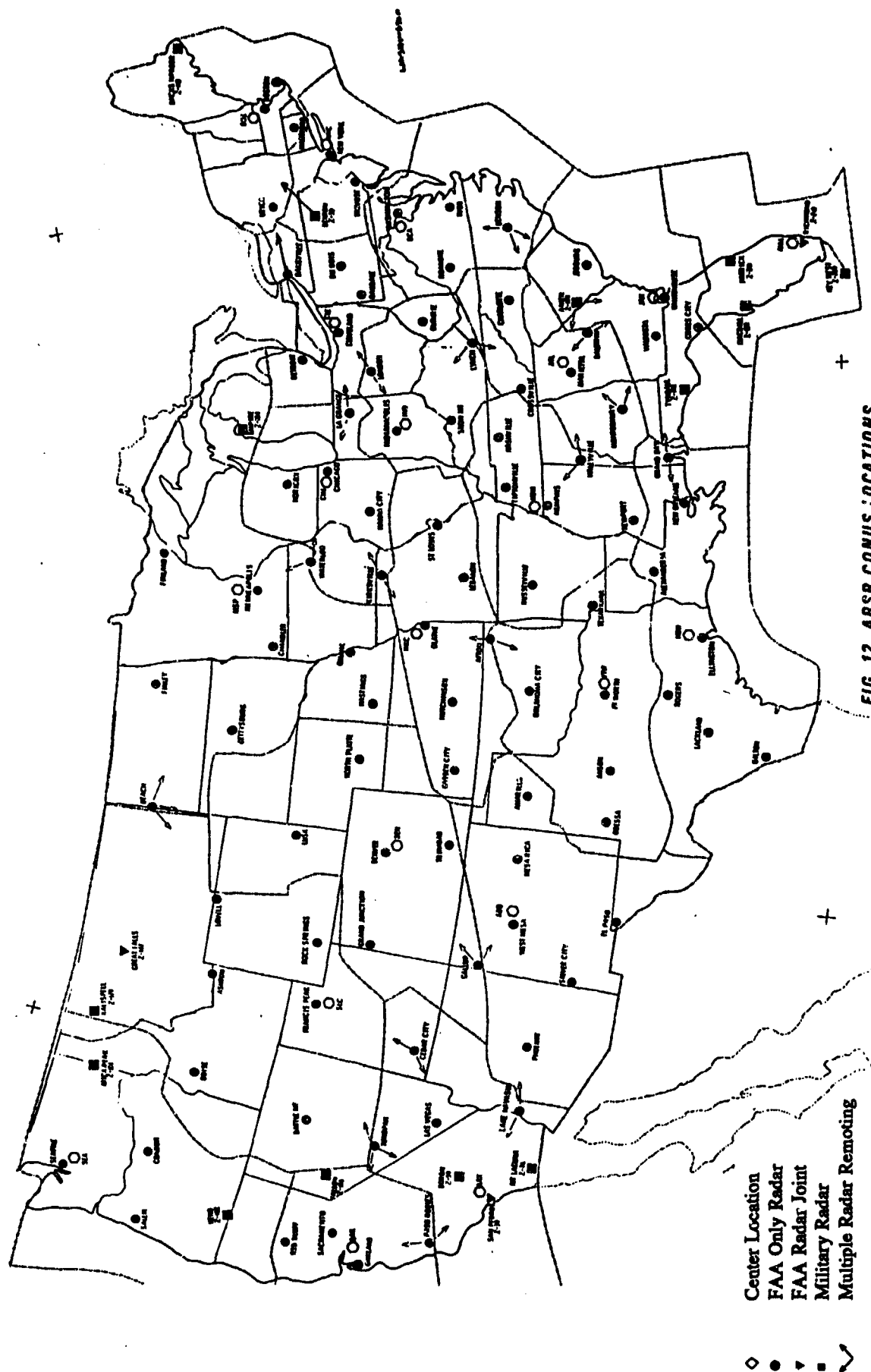


FIG. 12 ARSR CONUS LOCATIONS

Figure 1-1. ARSR CONUS Locations

- ◇ Center Location
- FAA Only Radar
- FAA Radar Joint
- △ Military Radar
- Multiple Radar Remoting

2. FUNCTIONS PERFORMED BY PRIMARY RADAR

While the bulk of surveillance data is now generated by secondary radar, primary radar continues to provide functions that beacon-radar cannot. Specifically, primary radar:

- Provides a backup in the event of airborne transponder failure.
- Provides a backup in the event of certain ATCRBS ground equipment failures.
- Enables surveillance of aircraft not equipped with beacon transponders (or whose transponders are intentionally turned off).
- Detects major weather systems and enables their real-time presentation on the controller's Plan View Display (PVD).
- "Reinforces" beacon target detection, providing additional input to the automated tracking process.

These functions, their impact on current ATC operations, and alternatives for providing them, are discussed in the following subsections.

2.1 BACKUP IN EVENT OF TRANSPONDER FAILURE

Description of Function -- Primary radar coverage exists over approximately 88 percent of CONUS at 6000 feet MSL, and is greater than that at altitudes above 6000 feet. ATCRBS provides coverage over substantially the same regions. (Most ATCRBS interrogators are colocated with primary radars; there are additionally 32 planned ATCRBS (beacon) - only sites.) Thus, in concept at least, primary radar serves as a backup to secondary radar for tracking Instrument Flight Rules (IFR) aircraft. Controllers at ZBW (Boston Air Route Traffic Control Center (ARTCC)) were interviewed for this investigation and indicated a strong preference for retaining primary radar for this role unless/until a suitable alternative is found. (Other major elements of the ATC system -- interfacility communications and computer processing -- have at least one backup system.)

To investigate the frequency of use of primary radar backup, "hard" statistical data on transponder failures was sought but not found. Interviews with controllers suggest that failures are seen once a day (high side) to once a week (low side) at an ARTCC. Transponder failures are significantly more common in smaller general aviation craft, which generally carry a single, relatively low-cost unit. Some military aircraft (e.g., the Navy P-3 series) also carry a single older transponder which fails relatively often.

Primary radar is not a full backup of the secondary; its coverage volume is somewhat smaller due to performance difference, and the existence at beacon-only surveillance sites. The difference in coverage altitudes is shown in Figure 2-1. Additionally, proper primary radar performance depends on the aircraft being sufficiently large to produce a strong echo, and generally being at a higher altitude than the minimum required for a beacon return. Also, primary radar tracking is unreliable when an aircraft is in traffic, because it is difficult to "hold track" when targets are maneuvering and closely spaced.

Primary radar surveillance can be critical in situations where transponder failure occurs coincident with the pilot becoming lost. However, since these cases usually involve smaller aircraft whose primary returns are too weak to maintain track, radar rarely aids in locating the aircraft. A recent study⁹ determined that primary radar is instrumental in providing successful assistance to an estimated 13 lost aircraft per year or 5 percent of all beacon and radar assists and 1 percent of assists which were unsuccessful. Based on analysis of National Transportation Safety Board (NTSB) statistics, the study concluded that deactivation of primary radar would result in an increase in the accident rate involving lost aircraft of 0.06 per year, with best and worst case confidence bounds of 0.01 and 0.3. That is, one additional accident each 18 years would be expected, if primary radar services were not available, due to a pilot becoming lost. It appears that this increase is so small because such accidents usually result almost wholly from pilot inexperience, and are about as likely to occur whether the aircraft is transponder equipped or not.

⁹Yesley, J. M. and Kitterman, R. W., *Impact of Primary Surveillance Radar on Lost Aircraft Accident Rate in the En Route Environment*, November 1991.

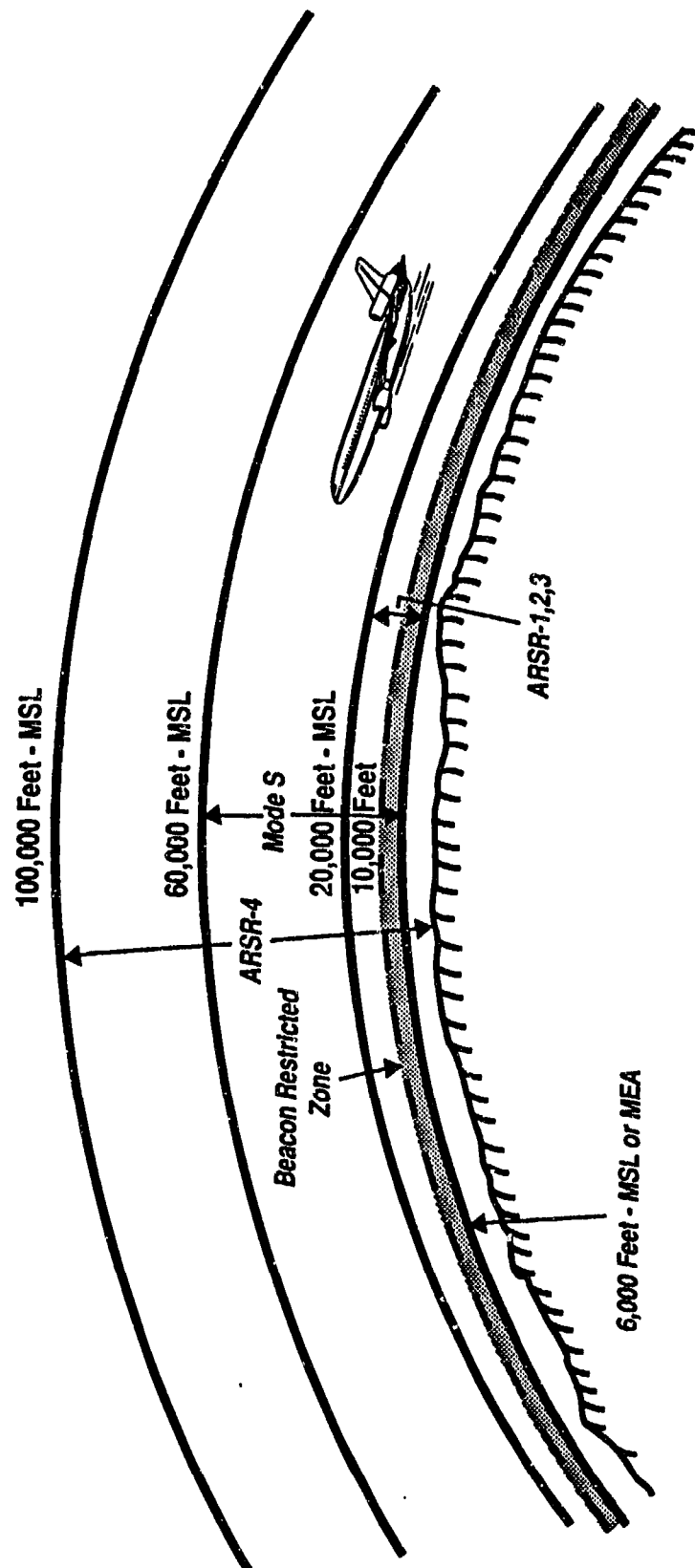


Figure 2-1. CONUS Radar Coverage
(from NAS-SS-1000, Vol. 1, p. 59)

Alternatives -- Several procedures are currently available for coping with transponder failure in IFR aircraft, depending on the circumstances. If navigation capability is not impaired, nonradar separation techniques can be employed with pilot voice-reporting of position. Pilots can revert to Visual Flight Rules (VFR) if appropriate. When the aircraft is lost, direction finding (DF) using communications signals is often effective. Presently there are 245 sites in the DF network, and an additional 125 are being installed.

In the future, improved/additional aircraft equipage can provide alternative backup techniques. For example, more reliable and/or redundant transponders may be developed/required. ADS, the automated version of voice-reporting of position, may become available. The key to its acceptance by recreational users will be avionics costs. Current low-end transponder cost, approximately \$1000, is a desirable goal.

2.2 BACKUP IN EVENT OF INTERROGATOR FAILURE

Description of Function -- Failure of the ATCRBS ground equipment could cause total loss of secondary-radar-derived surveillance data. Should this occur, primary radar can serve as a backup to secondary radar for tracking IFR aircraft. It is believed that this situation -- failure of the secondary while the primary remains operational -- occurs only rarely. One reason is that ground-based ATCRBS installations are dual-redundant. Also, since many critical components are common to both primary and secondary radar (e.g., antenna pedestal and drive, rotary joint, digitizer, prime power supply, communications), there is a high likelihood that a failure which causes loss of ATCRBS coverage will also result in loss of primary radar coverage. Moreover, the need for such a backup capability may not be strong: much of CONUS airspace already has coverage by at least two radar sites.

Alternatives -- An alternative to primary radar for this function is use of additional/redundant secondary radars (this is believed to be a common practice in Europe). Beacon radars provide better surveillance data than search radars. They are also cheaper to purchase (\$3.5M monopulse radar vs. \$10M (est.) primary radar) and maintain. In the future, ADS or possibly CIS may serve as alternatives.

2.3 NONCOOPERATIVE AIRCRAFT DETECTION

Description of Function -- Noncooperative aircraft may be divided into two classes -- those attempting to evade detection and those which simply do not have a transponder. Relative to the first class, air-search radar was first developed by the military for the detection of non-cooperative (in that case, hostile) aircraft. This function is still important, and now extends to other than hostile military aircraft (e.g., drug smugglers). A new generation of long-range radar, the ARSR-4, is being developed for this purpose, with enhanced ability to detect small, slow-moving and low-altitude aircraft. ARSR-4 output (search and weather) will be fed both to ARTCC centers for ATC and to military regional control centers to support the air defense and drug interdiction missions. FAA has no requirement to further support the latter missions, nor do current plans call for en route radars other than ARSR-4s to furnish surveillance data for non-ATC functions.

The other class of noncooperative aircraft belong to general aviation operators who do not have a transponder (primarily for cost reasons). While all aircraft operating under IFR carry transponders, and Federal Aviation Regulations (FARs) regularly reduce the regions of airspace in which nontransponder operation is permitted, a significant fraction of the U.S. aircraft fleet (about 30 percent of general aviation in 1992) is nonequipped. Most of these aircraft operate only in sparsely populated airspace, at low altitude. The separation services FAA provides to IFR and cooperating VFR aircraft include advisories on these aircraft where possible. However, current primary radar performance precludes routine tracking of nontransponder equipped small aircraft, and without altitude or identity information the effectiveness of the advisory service is at best minimal.

It is estimated¹⁰ that deactivation of the en route primary radars not part of the JSS would remove nontransponder aircraft surveillance coverage between 6000 feet (minimum radar coverage altitude) and 10,000 feet (maximum altitude for nontransponder aircraft) over 33 percent of the CONUS. The remaining 67 percent of the CONUS would either continue to be covered by terminal or JSS radars, or does not now have coverage. (The contemplated deactivation would also remove coverage for some regions above 10,000 feet. While

¹⁰Yesley, J.M., and Kitterman, R.W., *Effect of Primary Surveillance Radar on Mid-Air Collision Risk in the En Route Environment*, November 1991.

nonequipped aircraft are not authorized to be in these areas, occasional blunders do occur.) Without primary radar, controllers would no longer be able to provide advisories to IFR aircraft concerning the presence of VFR traffic in these regions. The referenced study considered 23 mid-air collisions over a 7-year span, and found that: the great majority (17) occurred below 6000 feet; and of the remaining 6 collisions, 4 were VFR/VFR. It predicts that shutting down en route radars will cause a negligible increase in the rate of IFR/VFR mid-air collisions (one additional accident in the next 30 years).

Since nontransponder operation is less constrained by the International Civil Aviation Organization (ICAO) regulations than by FAA regulations, nonequipped aircraft are occasionally also seen in offshore airspace, within FAA radar coverage. As seen in Figure 2-2, all 23 mid-air collisions studied occurred outside the proposed shutdown area. Virtually all such airspace

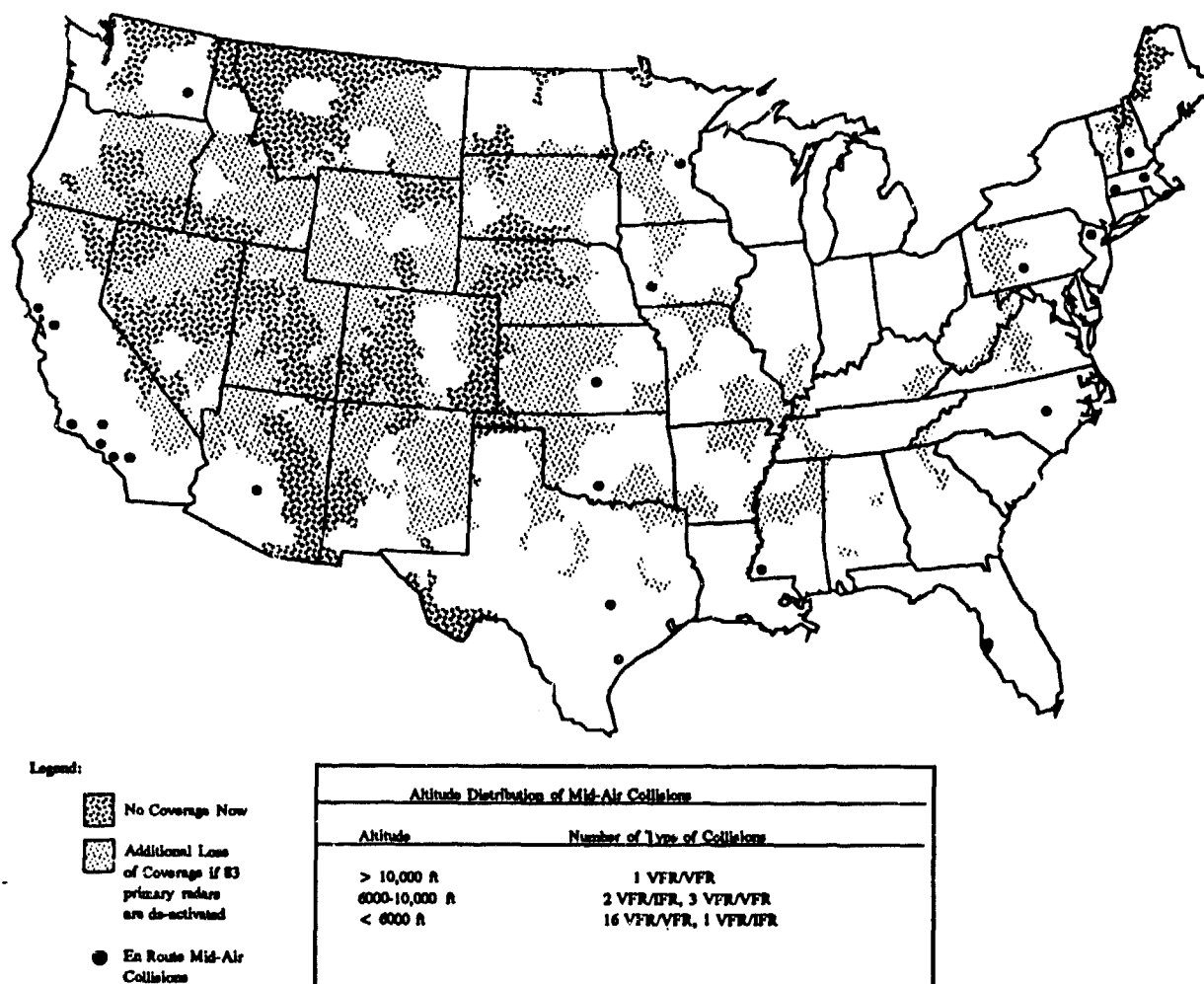


Figure 2-2. FAA Primary Radar Coverage at 6000 ft MEA

will continue to receive primary radar coverage (with ARSR-4s), as part of the air defense mission, and primary target data from these radars will continue to be used by the FAA.

Alternatives -- There is no alternative to primary radar for surveillance of aircraft intent on evading detection. However, in the case of benign, nonequipped aircraft, administrative rulemaking can lessen the need for primary radar. First, the FAA can continue to encourage transponder equipage by generally limiting the airspace where nonequipped aircraft may operate. Second, if separation of equipped and nonequipped aircraft is deemed critical in some of the regions of airspace where the latter are still allowed, then rulemaking which prevents their operation in those regions is an appropriate action. The inability of primary radar to track small aircraft reliably or determine their altitude makes it far less effective than ATCRBS in this application.

2.4 WEATHER DETECTION

Description of Function -- The process by which primary radar video are digitized for transmission to the center includes a limited capability to detect weather systems of sufficient intensity. Returns from a region of airspace attributed to "moderate" precipitation are displayed on the controller's PVD as a series of adjacent radial lines over the entire region of the weather system. "H"s are placed adjacent to the lines if the weather is deemed "heavy" (this is termed "two-level" weather capability -- see Figure 2-3). Because of its relatively long wavelength, L-band search radar gives only a rough indication of the shape, size and intensity level of weather systems. Controllers report frequent discrepancies between search radar-derived weather information and observations by pilots and national weather service radar reports. Typically these discrepancies are "false alarms" caused by ground clutter for lower beams or relative to precipitation in reasonably small areas -- either stand-alone on the periphery of large areas of actual precipitation. An additional drawback is that weather messages from pre-ARSR-4 search radars do not have altitude discrimination (the same vertical antenna pattern used for aircraft search is also used for weather).

ZBW controllers were interviewed concerning the utility of primary radar weather information. They consider current on-screen weather data only useful enough to give them a general indication that "something's out there." These controllers rely on other sources to

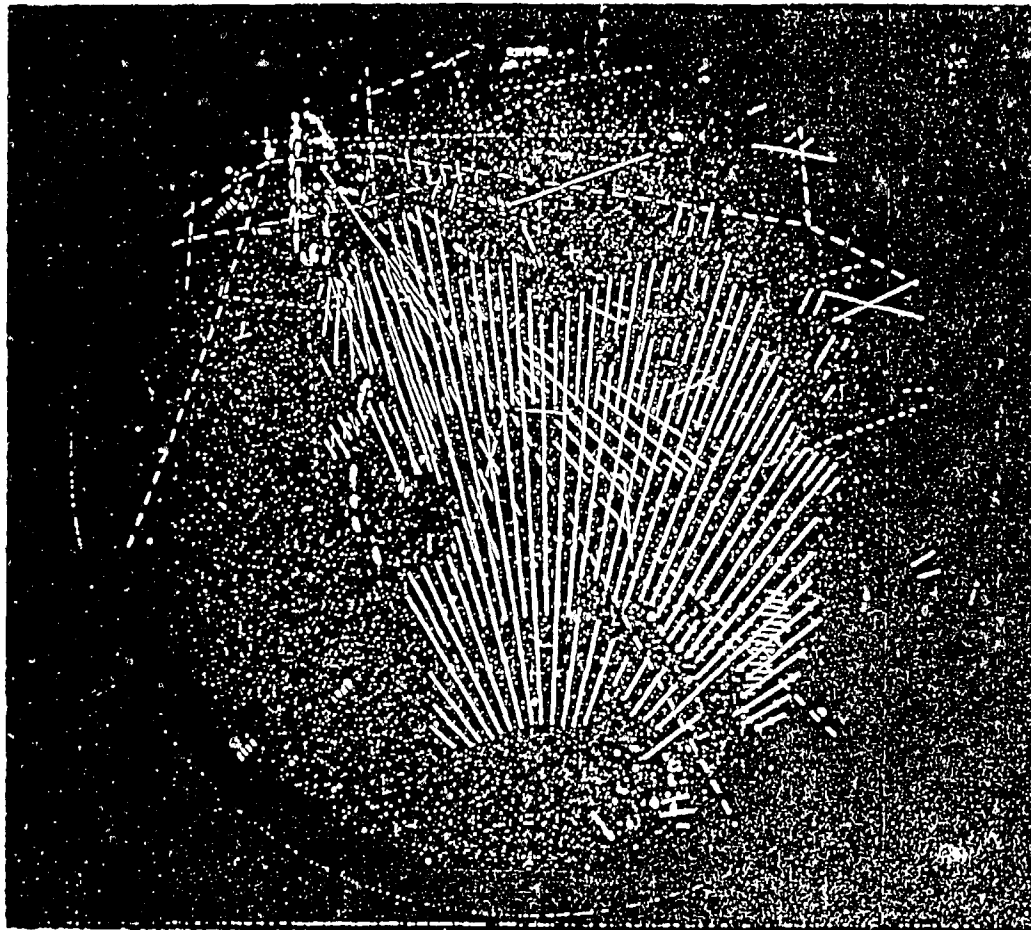


Figure 2-3. ARSR-Derived Weather Data on Controller's PVD

characterize the disturbance, and often suppress the display of "moderate" intensity weather. Some of the more experienced controllers lamented the loss of primary radar broadband analog video data (which was provided to the centers until the mid-1980s). With wideband video, controllers were able to reliably determine the outline of a region with intense weather, and thus make more efficient use of the airspace.

Alternatives -- Several FAA and joint agency programs currently in progress are developing national weather data products based on inputs from NWS radars and other sources. When available,¹¹ these weather products are expected to be far more extensive and accurate than ARSR-derived weather data. (There is some concern regarding the timeliness of new

¹¹Some near-real-time data is currently available commercially, and FAA now provides such data to centers; however, these data may only be viewed on separate (color) displays which are not readily accessible to all controllers.

weather data products -- see below.)

The time-frame in which improved weather information will be available at the controller's workstation is not certain. NEXRAD, a primary sensor for the improved weather products under development, will not be fully deployed until 1998. However, the mechanisms for creating data products, particularly the 23 Regional Aviation Weather Product Generators (RAWPG) and the associated distribution network, the Real-time Weather Processor (RWP), will not be completed until 2008. Moreover, the Advanced Automation System (AAS), the program under which new controller workstations capable of accepting and displaying RWP data, the Area Control Computer Complex (ACCC), is currently undergoing high-level review. Since it is not prudent to remove the current capability for providing real-time weather information at the controller's workstation without providing a replacement, these dates (availability of RWP and ACCC or replacement) are critical to the shutting down of primary radars.

Concern has been expressed regarding the timeliness (latency) associated with new weather data products, which will be presented to controllers in the future. While ARSR-derived data currently available is mediocre in quality, at least the controller can be assured that what he/she sees is representative of the current precipitation situation. Conversely, the NEXRAD radars, which are scheduled to provide precipitation data in the future, can take over 5 minutes to revisit a portion of the airspace volume; however, NEXRAD data are expected to be significantly more accurate than ARSR data. The National Center for Atmospheric Research (NCAR)¹² is presently conducting tests, at the direction of the FAA, to establish performance differences between ARSRs and NEXRAD, in terms of detectability and time delay (latency), and determine the effects of these differences on ATC system operation. Initial results are pending, and should be taken into account in decision-making regarding primary radar retention.

In the event that the ACCC installation date is later than can be tolerated for shutting down the non-JSS primary radars, or the ACCCs are cancelled as part of a restructuring of the AAS, it may be possible to define an "interim en route weather data improvement" project which would result in acceptable quality real-time weather data being available at the controller's workstation. The source of the data could be the NWS radars now in service (but scheduled to be replaced by NEXRAD). NWS data could be transmitted to centers over commercial or

¹²NCAR ASR/NEXRAD Comparison Study, Dr. B. Carmichael, NCAR (unpublished).

government telephone lines (meteorological data from six NWS sites is now transmitted to ZBW). The AAS ISSS consoles might serve as the display device. A more detailed investigation is required to validate this concept.

2.5 AUGMENTATION OF ATCRBS DATA

Description of Function -- Primary radar data is now reported to ARTCC automated tracking/surveillance processes in two forms by the digitizer:

- If a primary report does not correlate in position with a beacon report, it is reported as a "primary target," and its range and azimuth are provided. Center automation does not form tracks on such data, although controllers can force its tracking if they wish. A primary target is usually just displayed as an "x" on each scan, if tracked, and a "+" or a "." if not tracked, depending on its intensity.
- If a primary target correlates with a beacon target, the primary target report is not sent. Rather, a bit is set in the beacon target report to indicate "radar reinforcement."

Because secondary radar "false targets" are not uncommon, in instances where the controller has some uncertainty concerning a target, he/she can employ the reinforcement bit as another information source.

Alternatives -- Software-based processing techniques for reducing the incidence of beacon false targets have been developed, although none is implemented in an ARTCC. Since false targets are often the result of multipath, one effective technique involves mapping of the reflectors and associated multipath geometries into the track processing function for each radar site, and checking whenever the same beacon code appears twice on a scan (when this occurs, the location of one of the target reports is checked for consistency with one of the reflecting surfaces and the location of the other report). This process has been demonstrated in terminal processing software, is currently being implemented in upgrade ASR-9 beacon processing logic, and will be incorporated into Mode S.

3. EQUIPMENT INVOLVED AND COST IMPACT

This section addresses equipment- and cost-related issues involved in shutting down the FAA's FPS-20, ARSR-1, ARSR-2 and ARSR-3 primary radars. Subsection 3.1 provides a general description of the equipment expected to be involved in the shutdown. Subsection 3.2 addresses the specific equipment modifications required if the current primary/secondary sites are to become beacon-only sites. Subsection 3.3 provides information on the Remote Maintenance Monitoring System (RMMS). Subsection 3.4 provides rough cost estimates for the elements ("pieces") involved in a primary radar shutdown. Lastly, Subsection 3.5 combines the element costs and estimates the overall cost savings which would be achieved by shutting down the non-JSS search radars.

3.1 RADAR SITE EQUIPMENT DESCRIPTION

3.1.1 AN/FPS-20, ARSR-1 and ARSR-2

The FAA has acquired/purchased several generations of en route primary radars, and systems (installations) from each generation are still in service. During the 1940s, when radar surveillance began, the United States Air Force (USAF) procured the AN/FPS-20; subsequently, the USAF provided these systems (or data from these systems) to the FAA. Beginning in 1956, the FAA purchased Air Route Surveillance Radars (ARSRs) specifically designed for aircraft separation. A block diagram of a typical tube-type system (AN/FPS-20, ARSR-1, ARSR-2), is shown in Figure 3-1. The National Airspace System (NAS) currently includes 29 AN/FPS-20s and 47 ARSR-1s and -2s (76 altogether).

A secondary radar is collocated with each primary radar, a practice which began when secondary radar was first installed, in the 1950s. At the radar site, analog data from both the primary and secondary are processed by the Common Digitizer (CD) module, essentially independently. (At this time, one of the CD-2 family of digitizers is installed at most sites.) The radar scanning characteristics -- approximately one 360 deg rotation in 12 sec and 300 transmitted pulses each second -- result in multiple "hits" (approximately 30) on each target during one revolution. The CD-2 combines echoes from these "hits" into a single target report

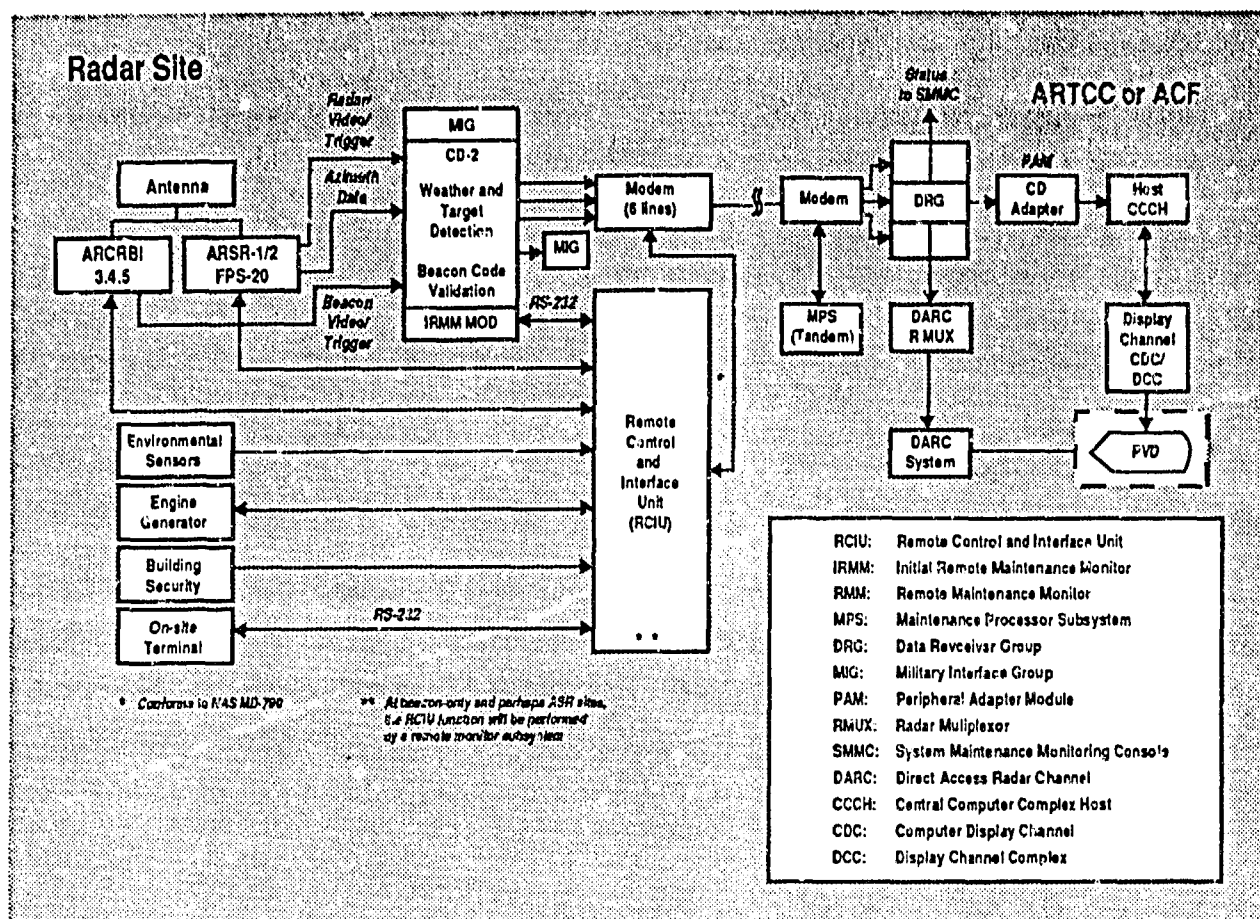


Figure 3-1. Block Diagram of FPS-20, ARSR-1, or ARSR-2 Site

(a digital message) which is forwarded to the center over landlines and/or microwave links. When the primary and secondary reports are considered to be in agreement, only the secondary's message is sent, with a "radar reinforcement" bit set to signify agreement. The CD-2 also identifies primary radar returns which appear to be due to precipitation, and constructs a polygon description of the affected area. This polygon is transmitted back in a third type of message, in addition to the primary and secondary aircraft target messages.

Typically, there are redundant transmission routes from each radar site to each destination center. (Information from radar sites near the periphery of an ARTCC service area are often sent to both the "owner" center and the nearest adjacent center. Adjacent centers are also

linked, providing another backup communications path). At each center, the digitized radar data are processed by the CCCH (Central Computer Complex Host, or simply "host"). The results are ultimately displayed on the controller's PVD. The DARC (Direct Access Radar Channel) serves as a backup to the host.

Several upgrades to the AN/FPS-20 and ARSR-1 and -2 series radars have been and continue to be implemented. The common digitizer is in fact an enhancement to the original installations (\$40M program). Initially, primary radar analog data, termed wideband video, was transmitted to the centers. After the introduction of digitizers, both wideband analog and digital data were sent to the centers. Since approximately 1985, only digital data has been communicated to off-site locations. Another important upgrade to these radars is the SSR/DMTI (Solid-State Receiver Digital Moving Target Indicator) capability, which identifies targets with a velocity component toward or away from the radar. In the region close to the radar transmitter, where returns from ground clutter are strong, only nonzero velocity Doppler targets are displayed. The SSR/DMTI program has already been completed.

3.1.2 ARSR-3 and ARSR-4

The ARSR-3 (see Figure 3-2) is a more modern radar than those addressed above, being developed in the 1970s. It is functionally similar to the FPS-20s and ARSR-1s and -2s, but employs more solid-state circuitry and uses a built-in data extractor rather than a common digitizer. Twenty-three ARSR-3s are currently in service -- a fraction of the number of the older tube-type units. Thus there are a total of 113 pre-ARSR-4 en route primary radars in the NAS today.

The existing radars require additional upgrades to meet FAA needs. One planned upgrade, the Remote Monitoring and Maintenance/Three-Level Weather (RMM/3LW), will improve the weather discrimination capability from the current two levels to three levels. (Initially, the ARSR-4 will provide three levels to controllers from the six available levels; all six levels will be used later for the Area Control Facility (ACF).) Another upgrade is the addition of RMM, which will allow maintenance personnel to access information concerning the equipment "health" without making an on-site visit.

The ARSR-3

- | | |
|---|--|
| 1 Emergency Power Diesel Generator Bldg | 13 Waveguide |
| 2 Prefabricated Metal Buildings | 14 12 5-11 Modular Sectioned Steel Tower |
| 3 Transformers | 15 Waveguide in Slatwork |
| 4 Geodesic Radoms, 57 1/2 ft Diameter | 16 Air Conditioner |
| 5 Aircraft Warning Lights | 17 Air Conditioner |
| 6 Lightning Rod | 18 Heat Exchangers |
| 7 Omni Directional Search Antenna | 19 Maintenance Display |
| 8 Reflector | 20 Receiver Processor |
| 9 Integrated Search Radar Feed Array | 21 Klystron Tubes |
| 10 Walkway | 22 Transmitter Modulator Cabinets |
| 11 Dual Drive Motors | 23 Buried Fuel Tank |
| 12 Rotary Joint | 24 EG Load Bank |

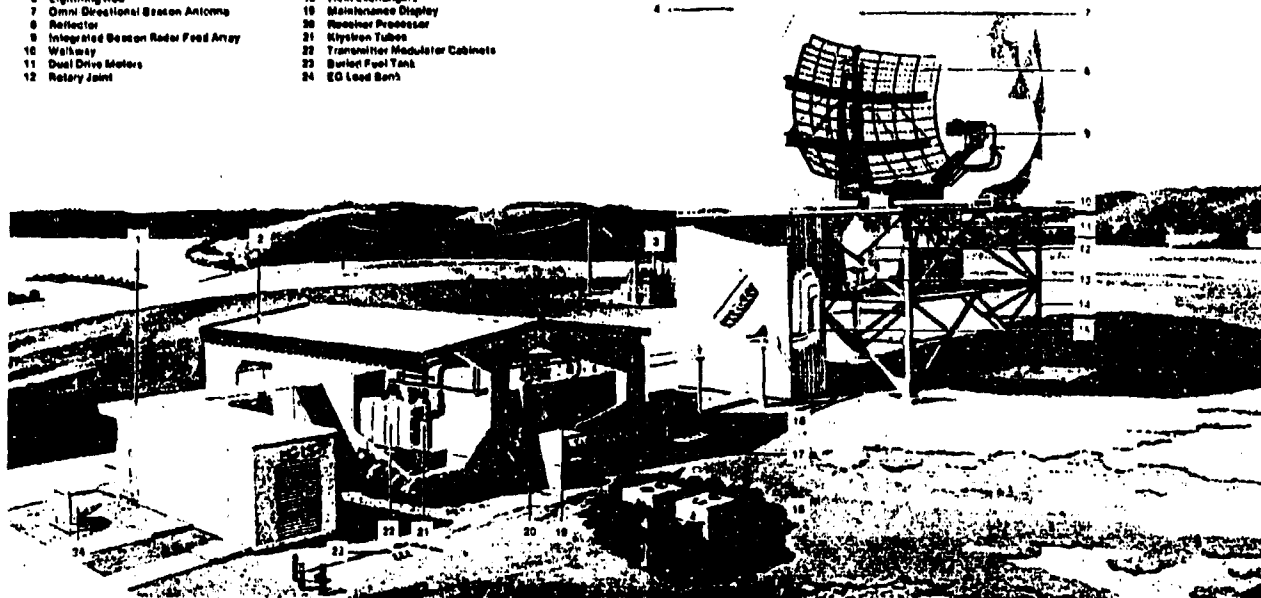


Figure 3-2. ARSR-3 Standard Configuration

The ARSR-4 development program -- a joint FAA/DOD effort -- is currently nearing completion (testing is ongoing). This modern radar is the first FAA system to employ solid-state transmitter technology, three-dimensional imaging, pulse compression, and other advanced signal processing techniques. Thirty-eight ARSR-4s will be deployed along the coast of the U.S., where they will provide both air defense and air traffic control surveillance capabilities.¹³ ARSR-4s are compatible with the Advanced Automation System software currently being developed for the centers and with the Area Control Facility future reconfiguration of the National Airspace System.

As the ARSR-4 is installed over the next few years, 10 of the existing ARSR-3 radars replaced by it may possibly be relocated ("leapfrogged") to current AN/FPS-20 and ARSR-1/2 sites, and the radars now installed in these sites may be scrapped. Table 3-1 summarizes the en route primary radar system as envisioned by the CIP in the year 2000.

¹³Four additional ARSR-4's are scheduled for installation at the FAA Academy (Oklahoma City, OK), and at naval installations on Hawaii, Guam, and Cuba.

Table 3-1. Planned En Route Primary Radars in the Year 2000

TYPE	NUMBER	COMMENTS
AN/FPS-20 ARSR-1 ARSR-2	60	Have been modified for SSR/DMTI, CD-2C; Planned upgrade for 3-level weather, RMM; Additional upgrade required for ACF/AAS compatibility
ARSR-3	23	Modifications in progress for 3-level weather, RMM
ARSR-4	42	All fully compatible with ACF/AAS

3.2 EQUIPMENT INVOLVED IN SHUTDOWN

3.2.1 Mechanical/Structural Issues

At an en route radar site, the secondary radar antenna is generally either mounted on the larger primary antenna or chin mounted. Many sites employ NADIF (NAFEC DIpole Fix) secondary surveillance antennas, which are integral to the primary radar antenna and make use of its reflector. The entire antenna structure is enclosed in a hemispherical radome. The search and beacon radar electronics are housed within or beneath the tower. The beacon electronics require one equipment rack; the remainder of the equipment (several racks) are devoted to the search radar, digitizer, and other common equipment.

Based on engineering judgment and discussions with FAA personnel, conversion of a dual-radar installation to a beacon-only site is expected to involve the following mechanical and structural changes:

- Removal of primary radar electronics from the equipment room.
- Removal of the radome.
- Replacement of the common pedestal, primary radar antenna and secondary radar antenna by a new secondary antenna, capable of operation without a radome.

Two types of Mode S antenna are currently in procurement, intended for terminal and en route radar installations. The terminal radar Mode S antenna will be mounted on top of an ASR primary "sail", and so is weather-proof. It employs a 4 x 16 element open array, with a conventional monopulse (sum and difference) pattern in the horizontal, and a fan-beam in the vertical dimension.

The en route antenna is electrically similar to and roughly the same size as the terminal one, differing primarily in its vertical illumination pattern. To concentrate its gain at the horizon in order to provide maximum detectability at long range, it employs a cosecant-squared vertical pattern rather than a fan-beam. Thus, the power-distribution networks in its individual vertical columns have components of different values from those in the terminal antenna. Two such antennas are to be employed at en route sites, under current plans, back-to-back. Since the primary sail requires weather protection, a radome will be required, as it is now. Simultaneous back-to-back operation of two Mode S/ATCRBS antennas in such close proximity leads to potential mutual interference problems; to counteract these, the currently planned en route antenna employs a much finer lattice structure on its back plane, which makes it also unsuitable for operation without a radome. The current radome degrades monopulse performance, so a new one is being developed for use with Mode S.

If primary radar were to be removed from en route sites, considerable savings could result by eliminating the radome *if terminal antennas could be modified for that application*. As noted above, modification would consist primarily of changes to the vertical feed networks to produce a cosecant-squared pattern rather than a fan beam. This appears attainable simply through use of components (splitters, attenuators) of different value.

En route radar scan rates are currently limited by mechanical constraints involving rotation of the large primary antenna. Replacing it with a secondary-only antenna would enable scan rates similar to those of terminal radars, and hence would eliminate the need for back-to-back operation. (At a 5-second update interval (12 rpm), a maximum unambiguous range of 240 nm can be realized, at a prf of 330, with 16 hits on target. This is consistent with the reduced fruit environment that will result from monopulse operation, and with Mode S data transmission requirements.) The ability of existing processing software to operate at these changed parameter values must be evaluated.

The costing discussions that follow therefore assume that a single antenna is employed at each secondary-only en route radar site, similar to a terminal radar ATCRBS antenna, with no radome.

The large pedestal now in use, which supports the massive primary antenna, requires frequent and sometimes extensive maintenance. (As part of scheduled maintenance, 15 to 18 pedestals are overhauled each year. Another 8 to 10 emergency repairs are performed annually.)¹⁴ A smaller pedestal, sized to the lighter beacon antenna, would be less expensive to construct and maintain, and could readily accommodate the higher scan rate.

3.2.2 Electrical Issues

Electrically, the primary and secondary radars are largely independent, as they must be, since secondary radars are sometimes deployed separately at so-called "beacon-only" sites. There are, however, three interfaces between the two that must be considered in converting a site to beacon-only operation (see Figure 3-3). These areas, and their resolution, are:

- *Beacon Trigger* -- In dual sites, beacon transmissions are triggered from the primary radar. However, the beacon can be made to self-trigger by providing an appropriate timing source.
- *Common Digitizer* -- The CD-2 will operate properly without primary radar returns; however, azimuth inputs from the antenna structure must be retained.
- *Beacon Performance Monitor* -- Can be retained without modification.

Put simply, there are no significant electrical issues associated with converting a dual radar installation to a beacon-only site.

¹⁴ CIP 44-43

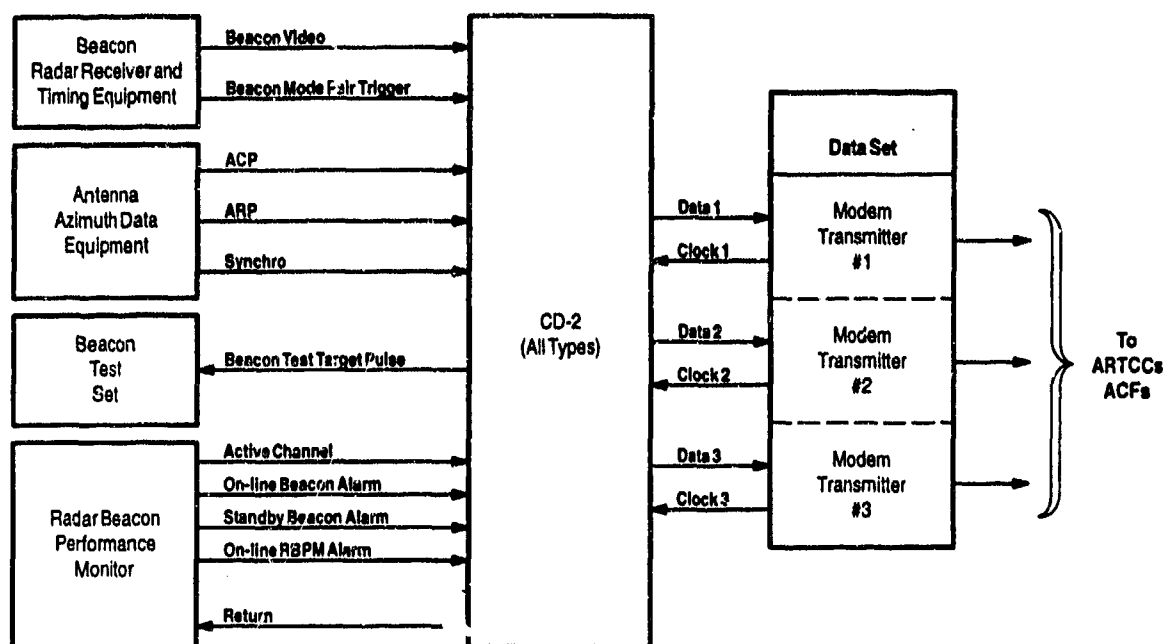


Figure 3-3. Data-Flow at Beacon-Only Site (Non-Mode S)

3.3 RMMS SYSTEM

The next generation Remote Maintenance Monitoring System (RMMS) planned for the ARTCC Maintenance Control Center (AMCC) and the General NAS/MCC (GMCC) will have a single Maintenance Processor Subsystem (MPS) located at ARTCC/ACF will service both the AMCC and GMCC. For RMMS purposes, the Interim Maintenance Control Software (IMCS) will continue to provide the maintenance functions for the ARSR-1, -2, -3 and the FPS radar systems until the Maintenance Control Software (MCS) is checked out. The discrete data associated with these radars will be acquired from the MPS by the Data Acquisition Subsystem (DAS) for display by the Real-time Status Display (RSD).

3.3.1 IMCS Transition Plan to MCS

At present, the IMCS software is operating with the ARSR-3 and the ARSR-1, -2 and FPS radars upgraded with the new CD-2 modifications. The MCS software for the next generation RMMS is being written at present.

The new replacement radars, namely Mode S and ARSR-4, will not be supported by IMCS until the IMCS DECODER processor for each radar is written. (The IMCS DECODER receives raw digitized data from the radars' sensors and reformats the data into a common data form for storage in the IMCS database file). In order to support the transition plan it is required that the IMCS software be included with the new MPS system. IMCS will continue to be included as part of the new MPS until the MCS software is operational.

3.3.2 Impact of Primary Radar Shutdown on Radar Maintenance

The impact on radar maintenance caused by shutdown of the primary radar within the ARSR-1, -2, -3 and FPS is as follows:

Radar Site.

- The Remote Control Interface Unit (RCIU) RMS software for the primary radar will be deleted. Any dependency of the secondary radar on the primary radar data information will be removed.
- CD-2 interfaces with the primary radar sensors will be removed.
- Maintenance Data Terminal (MDT) software to service the primary radar will be deleted and will include only the secondary radar.
- RMS timing for Primary to Secondary radars is to be redefined, i.e., Startup, Restart, On, etc. (Timing is initiated from the primary radar.)

AMCC Site.

- The software interface for the performance evaluation tests of ARSR and FPS radars will be reexamined and modified to include only the secondary radars.
- SDR files will be purged to exclude the primary radar.

The least affected by the shutdown of the primary radars is the MPS software.

Another aspect that must be investigated is whether the RMS modifications to the ARSR-1, -2, -3 and FPS, as part of a change to a secondary-only radar system, would adversely impact or support the transition plan to install the next generation Mode S radar systems.

3.4 ESTIMATED ELEMENT COSTS/SAVINGS

This subsection presents rough cost estimates for the elements involved in shutting down older primary radars. These elements include:

- Costs of modifications to convert a dual-radar installation to a beacon-only site (Subsection 3.4.1). This includes removal of old equipment and site cleanup. Installation of new Mode S beacon equipment is funded separately.
- Savings realized from cancelling ongoing CIP projects directed at modernizing installed primary radars (Subsection 3.4.2).
- Savings due to reduced maintenance of the en route radar sites (Subsection 3.4.3).

Estimated total costs, formed by aggregating the individual cost elements, are provided in Subsection 3.5. Note that estimates presented herein do not include the costs of associated systems which replace the functions now provided by primary radar (e.g., additional beacon-only sites, ADS). To the extent that such programs are undertaken or expanded to facilitate shutting down primary radars, their associated costs could be "charged against" the shutdown. Since the nature of such programs is at present unknown, it was not possible to estimate their costs. These should properly be included in the total when known.

3.4.1 Radar-Site Modifications

As described above in Subsection 3.2.1, modifications associated with converting a dual-radar installation to a beacon-only site are expected to involve: (1) removal of primary radar electronics from the equipment room; (2) replacement of the common pedestal, primary radar antenna and secondary radar antenna by a less massive pedestal and a new secondary open-array antenna capable of unprotected operation; and (3) removal of the radome.

Based on discussions with FAA personnel, *the estimated cost for these activities is between \$1.0M and \$2.0M per site* and therefore an average value of \$1.5M per site is used herein.

While site-modification cost estimates cannot be precise, because of different conditions at each site, they appear to be reasonable when contrasted with the costs for some of the systems involved. For example, the equipment cost for an ATCBI-5 secondary radar with an open array antenna is approximately \$3.16M, the cost for an en route site radome has been estimated as \$550K, and a full dual-antenna Mode S installation (with radome) costs \$4,84M.

3.4.2 Capital Investment Plan (CIP) Projects

Several CIP projects address en route primary radars, either entirely or in part. These projects, and the associated budgetary figures which relate directly to the postulated shutdown, are summarized in Table 3-2. *The total cost for the full and partial projects listed is \$336.0M* (sum of the amounts in the right-hand column). If an immediate shutdown of older en route primary radars were to occur, these costs could be foregone.

**Table 3-2. CIP En Route Radar Program Costs
(FY-93 Cost Estimates)**

PROJECT	NAME / DESCRIPTION	AMOUNT
24-15	<i>Long-Range Radar (LRR) Program</i> 10 ARSR-3 "leapfrog" relocations LRRs relocated as required (39 ARSR-4s being procured not included in "amount")	\$34.6M
44-39	<i>Relocate Air Route Surveillance Radars</i> Approximately 2 sites/year to be relocated	\$56.7M
44-40	<i>Long-Range Radar Improvements</i> Improvements to older LRRs: controls for ARSR-1 and -2s, cable trays cleaned-up, grounding upgraded	\$186.2
44-42	<i>Long-Range Radar Radome Replacement</i> Replace radomes at all existing LRR sites: most are 25 to 30 years old (signal distortion and maintenance are issues), and will not accommodate taller Mode S antenna	\$31.0M
44-43	<i>Radar Pedestal Vibration Analysis</i> Install vibration sensors and analysis equipment, in order to better manage maintenance activities	\$0.5M
	Solid State Transmitter	\$27.0M

Total: \$336.0M

3.4.3 Primary Radar Maintenance

Current FAA expenditures for maintenance of older en route sites are as follows: for all 43 AN/FPS-20 sites, \$0.9M per year (not including DOD costs) and for all 47 ARSR-1 and -2 sites, \$2.8M per year. Costs for 23 ARSR-3 sites were not found, but are estimated to be \$0.8M per year. A breakdown for the primary and secondary radars and common equipment was not available. However, based on its significantly larger size and higher transmitted power, it is expected that most of the cost can be attributed to the primary radar. Thus, an upper bound on the cost of maintaining the current primary radars is \$4.5M per year.

3.5 ESTIMATED TOTAL SAVINGS

From Section 3.4, it is clear that, in the long run, savings (based on foregone expenditures for radar upgrades and annual maintenance) can be achieved by shutting down the interior CONUS primary radars. However, in order to calculate total savings, a time-frame must be selected. (On the one hand, shutting down primaries in one year will cost more than it will save in that year. On the other hand, a very long time-frame, which will result in large predicted savings, is not realistic because conditions change too much.) For cost estimating purposes, the time-frame selected is the present to the year 2008. In 2008, real-time weather from new programs (NEXRAD, RAWPG, RWP, AAS) will be available to controllers, replacing an important primary radar function for which there is no present alternative. Also, by 2008, alternatives to primary radar for aircraft surveillance (increased transponder equipage, ADS) will be available.

Shutting down interior CONUS primary radars immediately, rather than in 2008, will involve the following costs:

- *\$124.5M Expenditures* -- for modifying 83 sites, at \$1.5M per site.
- *\$336.0M Savings* -- foregone expenditures for CIP projects in Table 3-2.

- **\$67.5M Savings** -- foregone expenditures for maintenance over 15 years at \$4.5M per year.¹⁵

The net savings associated with an immediate shutdown is \$279.0M over 15-year planning horizon, or an average of \$18.6M per year.

¹⁵Does not include potential watchstander - elimination savings, estimated at \$18.7M per year.

4. CONCLUSIONS

Table 4-1 presents a summary of the functions performed by primary radar. Functions are listed in order of decreasing value to the ATC system, together with possible alternative systems/procedures and the expected date of availability for the alternatives. The first two functions -- detection of real-time weather and nontransponder aircraft -- are *used by controllers every day*. The third function -- backup for failed transponders -- is employed on average perhaps once a week (based on anecdotal data). *Controllers at ZBW expressed a strong desire to retain primary radar* for these three functions. It appears that the fourth and fifth functions -- backup in the event of ATCRBS ground equipment failure and enhancement of secondary radar data -- could be eliminated without significant loss of ATC capability.

Table 4-1. Summary of En Route Primary Radar Functions

FUNCTION	NEED	ALTERNATIVES	AVAILABLE
Real-Time Weather Detection	High to Medium	NEXRAD/RWP/AAS New focused program	1998-2008 not planned
Nontransponder Aircraft Detection	Medium to Low	Increased transponder equipage ADS (or later CIS)	2000 unclear
Backup for Transponder Failure	Medium to Low	Voice position report Communications direction finding VFR operation	now now now
Backup for ATCRBS Ground Equipment Failure	Low	Additional secondary sites ADS (or later CIS)	not planned unclear
Improvement of Secondary Data	Low	Processing improvements	some in Mode S

A compelling, documented case for retaining primary radar to perform the first three functions is not evident. On the one hand, primary radar does not perform any of these functions extremely well. The primary radar weather capability is mediocre (two levels of precipitation and tends to overestimate activity with no altitude discrimination). Moreover, credible studies predict that the number of additional accidents which would result from removal of the radars would be almost insignificant: one additional IFR/VFR mid-air collision in the next 30 years (relates to second function), and one additional accident due to a pilot becoming lost in the next 18 years (relates to third function). In total, one additional accident in the next 11 years would be expected.

On the other hand, shutting down the primary radars immediately (before most replacement systems are on-line) would result in an overall loss of ATC surveillance capability. That is, an immediate shutdown would result in a decrease in the margin of safety. While the "bottom-line" measure of ATC performance -- accident rate -- might increase by only a small amount, some important intermediate level ATC performance factors, such as awareness of the overall traffic situation and ability to prevent near misses, would likely be impacted to a greater degree. *The most prudent course of action appears to be to retain the primary radars until full functional replacements -- i.e., systems which meet or exceed search radar capabilities -- are operational.*

If this tack is taken, *availability of a replacement for the real-time weather capability will be the governing factor in determining a potential shutdown date.* The planned replacement capability involves the NEXRAD weather radar sensor, RAWPG system for generating data for the controller, RWP distribution network, and ACCC controller displays. Scheduled completion for the RWP is 2008, and the AAS program under which the ACCCs are being developed is currently undergoing review. It might be possible to define an interim system for providing real-time weather to controllers from NWS radars using ISSS displays, and by doing that to advance the potential shutdown date, possibly to 1998.

GLOSSARY

AAS	Advanced Automation System
ACCC	Area Control Computer Complex
ACF	Area Control Facility
ADS	Automatic Dependent Surveillance
AERA	Automatic En Route Air Traffic Control
AMCC	ARTCC Maintenance Control Center
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Center
ASR	Aircraft Surveillance Radar
ATC	Air Traffic Control
ATCBI	Air Traffic Control Beacon Interrogators
ATCRBI	Air Traffic Control Radio Beacon Interrogators
ATCRBS	Air Traffic Control Radio Beacon System
CCCH	Central Computer Complex Host
CD	Common Digitizer
CIP	Capital Investment Plan
CIS	Cooperative Independent Surveillance
CONUS	Continental United States
DARC	Direct Access Radar Channel
DAS	Data Acquisition Subsystem
DF	Direction Finding
DMTI	Digital Moving Target Indicator
DOD	Department of Defense
DOT	Department of Transportation
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
GHz	Gigahertz
GMCC	General NAS/MCC
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMCS	Interim Maintenance Control Software
ISSS	Initial Sector Suite System
JSS	Joint Surveillance System

MCC	Maintenance Control Center
MCS	Maintenance Control Software
MDT	Maintenance Data Terminal
MPS	Maintenance Processor Subsystem
MHz	Megahertz
MSL	Mean Sea Level
NADIF	NAFEC Dipole Fix
NAS	National Airspace System
NCAR	National Center for Atmospheric Research
NEXRAD	Next Generation Weather Radar
nm	nautical mile
NTSB	National Transportation Safety Board
NWS	National Weather Service
PVD	Plan View Display
RAWPG	Regional Aviation Weather Product Generators
RCIU	Remote Control and Interface Unit
RMM	Remote Monitoring and Maintenance
RMMS	Remote Maintenance Monitoring System
RMS	Remote Maintenance Software
rpm	revolutions per minute
RSD	Real-time Status Display
RTCA	Radio Technical Commission for Aeronautics
RWP	Real-Time Weather Processor
SSR	Solid-State Receiver
TASC	The Analytic Sciences Corporation
TCAS	Traffic Alert and Collision Avoidance System
US	United States
USAF	United States Air Force
VFR	Visual Flight Rules
VHF	Very High Frequency
ZBW	Boston Air Route Traffic Control Center